Int. Conf. FOREST FIRE RESEARCH
Coimbra (1990) — Proceedings

FOREST FIRE BEHAVIOR RESEARCH IN CANADA

R.S. McALPINE*, B.J. STOCKS**, C.E. VAN WAGNER*, B.D. LAWSON***, M.E. ALEXANDER**** & T.J. LYNHAM**

** Forestry Canada, Petawawa National Forestry Institute, Ontario, Canada.*
*** Forestry Canada, Great Lakes Forestry Centre, Ontario, Canada.*
**** Forestry Canada, Pacific Forestry Centre, Victoria, Canada.*
***** Forestry Canada, Northern Forestry Centre, Alberta, Canada.*

SUMMARY

From the beginning of fire research efforts in Canada, forest fire behavior research has been empirical in nature, producing fire behavior predictions based on models derived from field experiments. The models relate fire behavior to weather based fuel moisture codes and relative fire behavior indexes. Experimental fire sizes attempt to reflect equilibrium fire behavior conditions for the chosen fuel/weather conditions. Laboratory-based research in moisture physics and heat transfer theory provide the framework by which the field data are analyzed. The Canadian Forest Fire Behavior Prediction System is the culmination of this research on quantitative fire behavior. The ongoing goal is the production of a universal fire behavior model combining field experimental evidence with physically-based models.

INTRODUCTION.

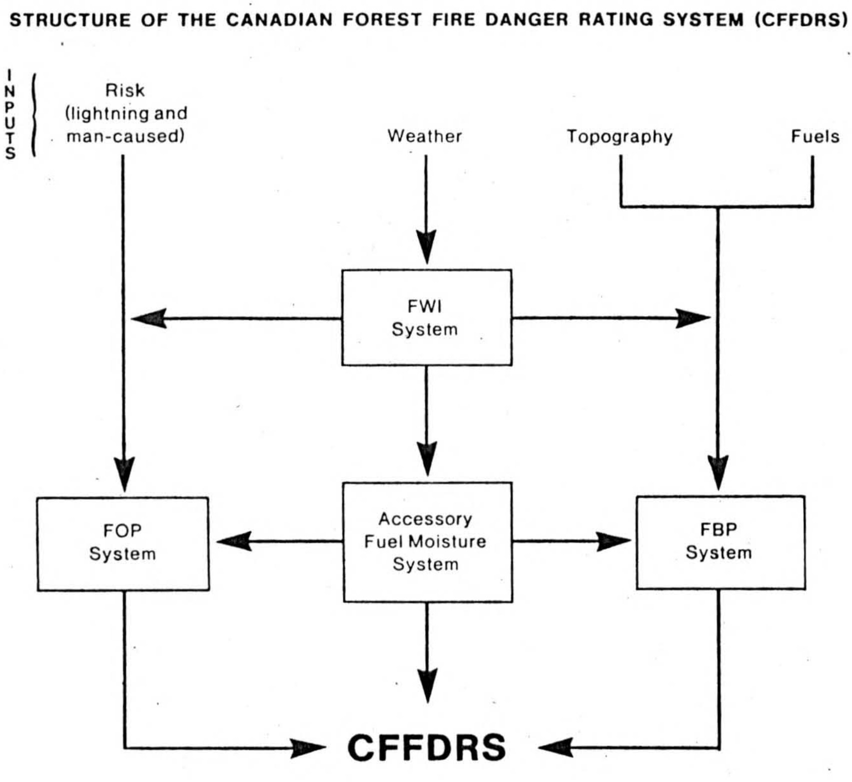
The federal forestry service began forest fire research in Canada in the early 1920s. The initial research thrust was the development of fire hazard rating systems which would indicate the predisposition of forested areas to fire (Wright 1932). Field research stations were established for varying lengths of time across Canada, in order to investigate the relationships between weather elements, fuel moisture, and fire behavior. These fire hazard rating systems utilized simple weather measurements, taken daily, to estimate fire potential for specific regions of Canada. Over the next 40 years, four successive fire danger rating systems formed the first steps towards a quantitative fire behavior prediction system for Canada.

In 1970 the Canadian Forest Fire Weather Index (FWI) System was released, representing the first national system of fire danger rating in Canada (Canadian Forestry Service 1984, Van Wagner 1987). The earlier regional danger rating systems could not meet the demands of increasingly sophisticated fire management agencies, necessitating the development of a more advanced system. The FWI System consists of three fuel moisture codes and three fire behavior indexes that indicate relative fuel moisture and fire behavior potential. These relative codes and indexes facilitate comparison of fire potential among regions, without the added complications of fuel type and topography. The FWI System is a descendant of previous Canadian danger rating systems, retaining the best features of previous systems, enhancing some elements, and adding new components where necessary.

Following the release of the FWI System in 1970, fire researchers focused their efforts on the development of quantitative fire behavior prediction models for major Canadian fuel types, through extensive experimental burning programs and detailed monitoring of wildfires. In 1984 the Canadian Forest Fire Behavior Prediction (FBP) System (Lawson et al. 1985) was introduced across Canada in the form of an interim edition. The FBP System was subsequently expanded into a comprehensive system for quantitatively predicting many aspects of fire behavior (rate of spread, fuel consumption, fire intensity, crown fire potential, and fire growth). This complete version of the FBP System was released to fire management agencies in 1989.

Both the FWI System and the FBP System are subsystems of the Canadian Forest Fire Danger Rating System (CFFDRS) (Figure 1). (Stocks et al. 1989). Not all CFFDRS subsystems are complete at this time; however, when complete, the CFFDRS will provide a comprehensive national system for fire danger rating.

The research methods leading to the FBP System, the considerations made, both theoretical and practical, and the structure of the FBP System itself are the primary subjects of this paper. Since forest fire research began in this country almost 70 years ago, many changes have taken place in research methods and application technology; however, all fire behavior research through the years has contributed directly or indirectly to the current FBP System.



CFFDRS subsystems

FWI System	Canadian Forest Fire Weather Index System (4th edition 1984)
FOP System	Canadian Forest Fire Occurence Prediction System (under consideration)
FBP System	Canadian Forest Fire Behavior Prediction System (draft released 1989)

Accessory Fuel Moisture System - In various stages of development.

Figure 1. Simplified structure diagram for the Canadian Forest Fire Danger Rating System (CFFDRS).

Fire behavior research in Canada has always been largely empirical in nature. Data from experimental fires, well-documented wildfires, and operational prescribed fires, are analyzed with simple mathematical models and correlation techniques within a theoretical framework provided by moisture physics and heat transfer principles.

Early experimental fires were small in scale, ignited from a point source and limited to 2 minutes in duration. These fires were documented with notations made on the fire vigour, behavior and final size, along with the standard weather measurements (Paul 1969). These test fire results, along with data from fuel moisture studies, formed the basis for the early fire danger rating systems and the subsequent FWI System. These small-scale fires were conducted from the mid 1930s to the mid 1960s, resulting in a database of more than 20,000 fire observations. This type of experimental fire, however, could not provide quantitative estimates of full-scale equilibrium fire behavior for specific fuel/weather conditions. To solve the problem, experimental plot sizes were increased and ignition techniques were altered to allow fires to exhibit the maximum likely fire behavior for the given environmental conditions.

Larger plots, ignited with a line of fire along the upwind edge, allow the experimental fire to achieve equilibrium fire behavior. Study areas are selected to eliminate the influence of variation in fuels and topography. Variation between plots is therefore kept to a minimum; observed differences in fire behavior being attributable to the effect of antecedent and current weather, as reflected in the FWI System. A weather station is established on the site to monitor daily weather so that the fuel moisture codes and fire behavior indices of the FWI System can be computed. Prior to ignition, ground, surface, and crown fuels are inventoried to characterize fuel loads and moisture contents. During the fire, measurements are made of the rate of fire spread and general fire characteristics (through notation and photography). Immediately after the fire, the remaining unburned fuel is inventoried to determine fuel consumption, the value of which is combined with the rate of spread and a standard value for heat of combustion to determine the fire intensity (Byram 1959). The values for rate of spread, fuel consumption and fire intensity are correlated with the indices of the FWI System to provide predictive models for fire behavior. Fuel types within the FBP System are discrete, and were selected for study based on the needs of fire managers (problematic fuel type) and the interest of researchers (distinctly different fuel type) (Alexander and Quintilio 1990).

This form of experimental fire and pattern of model development has continued to the present day; however, another ignition technique has also been used in recent years. When wildfires start, they spread from a single point source. Obviously, a fire does not exhibit the same behavior characteristics at the time of point ignition, as those of a well established fire. This period of increasing vigour and accelerating rate of spread represents, in most cases, the only period during which the fire can be successfully controlled. This acceleration period is also being studied with experimental fires, using many of the same procedures as the line source ignition fires mentioned above, the exception being the ignition technique, and the measurement of intermediate fire spread rates from the time of ignition until the plot boundary is reached or an equilibrium spread rate is achieved (Alexander and Quintilio 1990). Laboratory study of this phase of fire growth has also been undertaken to provide a framework for further analysis (McAlpine 1988, 1989).

More than 300 experimental fires have been conducted over the past 20 years in several fuel complexes across Canada including logging slash, coniferous and hardwood forests (e.g., Lawson and Taylor 1986, Lawson 1973, Stocks 1989, Quintilio et al. 1977). Plot sizes have varied from 0.1 to 3.0 ha. The experimental fires have covered an enormous range in fire behavior, from low-vigour surface fires with flames 20 to 30 cm long, to high-intensity crown fires with flame heights exceeding 40 m.

The fire behavior data collected to date could not have been obtained without the full cooperation of Canadian provincial and territorial fire management agencies through the provision of suitable experimental burning areas, logistical support, and manpower for ignition and control.

WILDFIRE CASE HISTORIES

Although experimental fires are conducted over as broad a range in burning conditions as possible, experimental fires at the extreme end of the spectrum become difficult to schedule and manage due to political and resource constraints. Although data collected on major wildfires must be more general in nature (e.g., lack of fuel sampling capability and on-site weather measurements), often these fires provide the only opportunity to document high-intensity fire behavior. Therefore, a concerted effort has been made to investigate and document major Canadian wildfires, resulting in data from more than 50 well documented wildfires being incorporated into the FBP System database. Ideally, data on wildfires is collected directly by researchers during the major fire runs (e.g., Stocks and Flannigan 1987); however, such opportunities are rare. More often, wildfire documentation occurs after the fact, and relies on key on-site observations made by fire management personnel and the reconstruction of weather conditions during the fire (e.g., Alexander and Lanoville 1987). An example of one such wildfire is shown in Figure 2. During the 1985 fire season, the British Columbia Forest Service evaluated the suitability of using airborne infrared line scanning technology for fire detection and fire mapping, as an aid in suppression tactics. Infrared mapping can also provide the necessary documentation of spread rate, perimeter location and size of a wildfire at various time intervals. This is illustrated in Figure 2, where the fire behavior of the initial run was recorded by infrared line scanner and later analyzed to determine spread rate and perimeter.

OPERATIONAL PRESCRIBED FIRES

With a few exceptions (e.g., Hawkes 1985) the use of operational prescribed fires for data collection in the FBP System has been largely limited to acquiring data on fuel consumption in relation to components of the FWI System. The complex ignition patterns generally associated with broadcast burning of logging slash restrict opportunities to obtain representative rate of spread measurements.

THE CANADIAN FOREST FIRE BEHAVIOR PREDICTION (FBP) SYSTEM

All available data from documentation of experimental fires, wildfires, and operational prescribed fires forms the data base from which the FBP System was developed. The FBP System provides estimates of rate of spread, fuel consumption, fire intensity, and degree of crown involvement for 16 discrete Canadian fuel types. As

Cranbrook Fire IR #6, British Columbia, Canada

Geographical Location: 49°37.5' N, 115°37.3 W.

Time/Date of Origin: 1530 h MDT, July 8, 1985

Fuels: FBP System Fuel Type C-7, open ponderosa pine - Douglas-fir (15 m stand height & 3 m crown base height), cured grass and logging slash from partial cut.

Topography: flat, 900 m MSL

Weather: 1300 h MDT observations recorded at Cranbrook AES station (8km west of fire area, 939 m MSL) - Temp 33°C, RH 19%, 10-m winds 270° @ 18 km/h. Average wind speed during fire run (1530-1740 h MDT) 24 km/h.

FWI System: FFMC 96, DMC 96, DC 487, ISI 33, BUI 129, FWI 76, (@ time of the fire).

Fire Behavior: Elapsed time since ignition and infrared mapping at 1740 h MDT - 130 min.

Parameter	Observed	Predicted
Head Fire ROS (m/min)	16.5	14.7
Fuel Consumption (kg/m^2)	–	3.7
Head Fire Intensity (kW/m)	–	16,487
Type of Fire & Crown Fraction Burned (CFB)	continuous crown fire	continuous crown fire (CFB 0.94)
Total Spread Distance (m)	2,140 *	1,700
Fire Area (ha)	67	79
Fire Perimeter (m)	4,234	3,810
Elliptical L/B	2.29 **	2.87

* Excluding the spot fires east of the river.

** Reflects intensive suppression action along northern flank of fire from airtanker drops of chemical retardant.

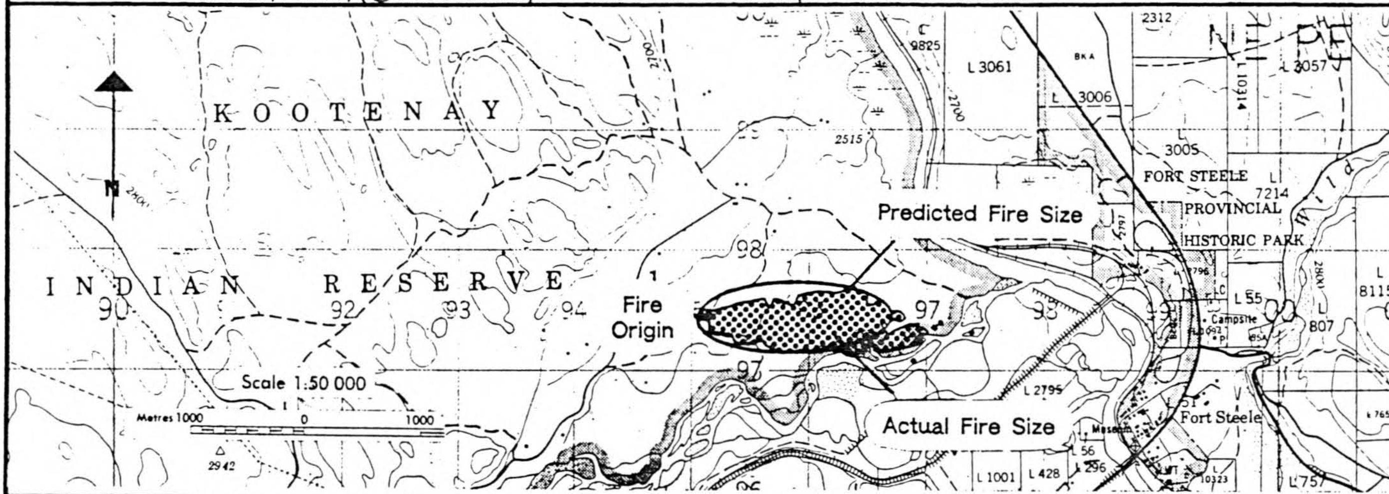


Figure 2. Hindsight analysis of a well-documented wildfire involving the Canadian Forest Fire Behavior prediction System. The shaded area represtents the actual area burned by the wildfire at the time of mapping.

secondary outputs, with the aid of an elliptical fire growth model (Alexander 1985), spread distance, elliptical fire area, and perimeter are also predicted. The effects of ground slope, fine fuel moisture, wind speed, variable fuel consumption and foliar moisture content on the spread rate of the fire have been taken into account (Van Wagner 1989). A computational scheme for estimating the foliar moisture content of conifers has also been developed. Since the introduction of the FBP System, excellent results have been reported both in operational use, in a real-time sense (DeGroot 1989), and in analyses of well-documented wildfires after-the-fact (Hirsch 1989, Stocks 1988, Alexander 1990, Stocks and Flannigan 1987).

TECHNOLOGY TRANSFER

Most of the forest fire research done in Canada is undertaken by a federal government agency, Forestry Canada. However, the responsibility for forest land management, including fire protection and use, rests with other federal provincial and territorial government agencies. Research products such as the FBP System must therefore be introduced to user agencies and accepted on the basis of merit and performance. Acceptance is enhanced by involving the "client" in both identifying the research need and participating in the research and development process.

In 1984, an interim edition of the rate of spread, type of fire and elliptical fire growth components of the FBP System for 14 fuel types was released for user trials. This action resulted in the demand for completion of the remaining components, the addition of more fuel types, more inputs and greater flexibility. This was viewed as a positive result of the early introduction of an incomplete product, because user agencies were being encouraged to play an active role in the research and development process. This role has changed from collection of field verification data for model testing to early identification of in-house technology transfer concepts that can be worked on at the same time the system itself is still being developed.

The FBP System has been packaged into a variety of formats to allow user agencies of varying levels of sophistication to utilize as much of what the system has to offer as they desire (e.g., McAlpine 1986). The computerization of the FBP System has enhanced computer assisted fire management systems, thereby increasing the effectiveness of resource deployment and utilization. Interpretive aids and other guides have also been prepared (Alexander et al. 1989, Stocks et al. 1990).

Forestry Canada fire researchers have actively participated as instructors in many user agency training courses since 1984. Forestry Canada has also sponsored instructional forums of its own. For example in December 1989 a 2-day national technology and information transfer workshop was organized in order to expose Canadian fire management agencies and other interested groups (e.g., university and technical forestry schools, the private sector) to the first complete edition of the FBP System and to solicit their comments prior to final publication. All of these activities have facilitated the free flow of ideas from researcher to end user and vice-versa. This kind of exchange has benefited both parties by allowing Forestry Canada fire researchers to see exactly the concerns of fire managers, and by allowing fire managers to better understand the system being introduced.

POSTSCRIPT

The ultimate aim of forest fire behavior research is the accurate prediction of fire behavior under all possible combinations of fuel, topography, and weather. This is indeed a lofty ideal. Despite significant progress in studying fire behavior during the past 65 years, not only in Canada, but in the United States, Australia, and the Soviet Union, the development of a completely generalized physical theory-based model of fire behavior, with universal applicability, remains a continuing research challenge. The inherent complexity of the fire environment places very real limitations on a fire researcher's ability to understand and describe fire behavior completely. Scientifically, the approaches to modelling forest fire behavior have so far involved mathematical analysis of fundamental combustion physics and chemistry, laboratory test fires, and field observation of real forest fires (Van Wagner 1985). Significant attempts have been made to model free-burning fires theoretically, but to date, the results offer little promise that fire spread rates and intensities can be reliably predicted over the full range of environmental conditions required. The FBP System, which is used by all fire management agencies in Canada, is a blend of art and science, and in our opinion represents the only realistic means of satisfying present and immediate future needs for quantitative fire behavior information.

ACKNOWLEDGMENTS

The infrared map and fire report data used in preparing Figure 2 were kindly provided by P.L. Fuglem, Planning, Development and Research Section, Protection Branch, British Columbia Forest Service, Victoria, B.C.

LITERATURE CITED

Alexander, M.E. 1985. Estimating the length-to-breadth ratio of elliptical forest fire patterns. Paper presented at the Eighth Natl. Conf. on Fire and Forest Meteorology (Apr. 29 - May 2, 1985). Detroit, Mich. 18 pp.

Alexander, M.E. 1990. The 1985 Butte Fire in central Idaho: a Canadian perspective on the associated burning conditions. In Proceedings from the Fire and the Environment: Ecological & Cultural Perspectives Interl. Symposium (March 20-24, Knoxville, Tennessee). University of Tennessee, Knoxville, Tennessee. (in press.)

Alexander, M.E., and R.A. Lanoville. 1987. Wildfires as a source of fire behavior data: A case study from N.W.T., Canada. Ninth Conf. on Fire and Forest Meteorology (Apr. 21-24, 1987) San Diego, California. Amer. Met. Soc. Boston, Mass.

Alexander, M.E., W.J. DeGroot, K.G. Hirsch, and R.A. Lanoville. 1989. Use of posters for interpreting fire behavior and danger research. Fire Mgmt. Notes. 50(2) p 41-44.

Alexander, M.E. and D. Quintilio. 1990. Perspectives on experimental fires in Canadian forestry research. Mathl. Comput. Modelling, (in press)

Byram, G.M. 1959. Combustion of forest fuels. Pages 61-89. In Forest Fire: Control and Use, K.P. Davis (ed.). McGraw-Hill, N.Y.

Canadian Forestry Service. 1984. Tables for the Canadian Forest Fire Weather Index System. Fourth edition. Environ. Can., Can. For. Serv., Ottawa, Ont. For. Tech. Rep. 25. 48 p.

De Groot, W.J. 1989. Technology transfer in Saskatchewan: Operational use of the Canadian Forest Fire Danger Rating System. Pages 327-332. In MacIver, D.C., et. al., eds. Proc. Tenth conf. Fire and Forest Meteorol. (Apr. 17-21, 1989) Ottawa, Ontario.

Hawkes, B.C. 1985. Vedder mountain site rehabilitation prescribed burn. Pages 210-211 In Proc. Workshop Prescribed Fire by Aerial Ignition (Oct. 30 - Nov. 1, 1984, Missoula, Mt.). Intermountian Fire Counc., Missoula, Mt. USA.

Hirsch, K.G. 1989. Analysis of the fire behavior associated with three 1988 spring wild fires in Central Canada. Pages 416-425. In MacIver, D.C., et. al., eds. Proc. Tenth conf. Fire and Forest Meteorol. (Apr. 17-21, 1989) Ottawa, Ontario.

Lawson, B.D. 1973. Fire behavior in lodgepole pine stands related to the Canadian Fire Weather Index. Environ. Can., Can. For. Serv., Pac. For. Res. Cent., Victoria, B.C. Inf. Rep. BC-X-76. 26 p.

Lawson, B.D., B.J. Stocks, M.E. Alexander, and C.E. Van Wagner. 1985. A system for predicting fire behavior in Canadian forests. Pages 6-16. In Proc. Eighth Conf. Fire and For. Meteorol. (Apr. 29-May 2, Detroit, Mich.). Soc. Am. For., Bethesda, Md. SAF Publ. 85-04.

Lawson, B.D., and S.W. Taylor. 1986. Preliminary evaluation of prescribed fire impact relationships and predictors for spruce balsam slash. Pages 48-68 In Proc of Fire Management Symposium, Central Interior Fire Protection Comm., Prince George, B.C.

McAlpine, R.S. 1986. Forest fire growth calculator. Govt. Can., Can. For. Serv., North. For. Cent., Edmonton, Alta. For. Manage. Note No. 35. 8 p.

McAlpine, R.S. 1988. The acceleration of point source fire to equilibrium spread. M.Sc. Thesis, Univ. Mont., Missoula. 130 p.

McAlpine, R.S. 1989. Temporal variation in elliptical forest fire shapes. Can. J. For. Res. 19:1496-1500

Paul, P.M. 1969. Field practices in forest fire danger rating. Can. Dep. Fish. and For., Can. For. Serv., For. Fire Res. Instit., Ottawa, Ont. Inf. Rep. FF-X-20. 17 p. + Appendices.

Quintilio, D.; G.R. Fahnstock, and D.E. Dube. 1977. Fire behavior in upland jack pine: the Darwin Lake Project. Fish. and Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alta. Inf. Rep NOR-X-174. 49p.

Stocks, B.J.; M.D. Flannigan. 1987. Analysis of the behavior and associated weather for a 1986 northwestern Ontario wildfire: Red Lake Number 7. Pages 94-100. In Postprint Volume of the Ninth Conference on Fire and Forest Meteorology (April 21-24, San Diego, California). Am. Meteor. Soc., Boston, Massachusetts.

Stocks, B.J. 1988. Forest fire close to home: Terrace Bay #7/86. Proc. Symp. and Workshop Protecting People and Homes from Wildfire in the Interior West, USDA For. Serv. Gen. Tech. Rep. INT-251.

Stocks, B.J. 1989. Fire behavior in mature Jack Pine. Can. J. For. Res. 19:783-790

Stocks, B.J.; B.D. Lawson; M.E. Alexander; C.E. Van Wagner, R.S. McAlpine; T.J. Lynham; and D.E. Dube. 1989. Canadian Forest Fire Danger Rating System: an Overview. For. Chron. 65(6):450-457.

Stocks, B.J., D.J. McRae, T.J. Lynham, and G.R. Hartley. 1990. A photo-series for assessing fuels in natural forest stands in Northern Ontario. Forestry Canada, Ontario Region COFRDA report 3304.

Van Wagner, C.E. 1985. Fire behavior modelling - how to blend art and science. Pages 3-5. In Proc. Eighth Conf. Fire and For. Meteorol. (Apr. 29-May 2, Detroit, Mich.). Soc. Am. For., Bethesda, Md. SAF Publ. 85-04.

Van Wagner, C.E. 1987. Development and structure of the Canadian Forest Fire Weather Index System. Govt. Can., Can. For. Serv., Ottawa, Ont. For. Tech. Rep. 35.

Van Wagner, C.E. 1989. Prediction of crown fire behavior in conifer stands. Pages 207-212 in Proceedings of Tenth Conference of Fire and Forest Meteorology (April 17-21, Ottawa, Ontario). Forestry Canada, Ottawa, Ontario.

Wright, J.G. 1932. Forest fire hazard research as developed and conducted at the Petawawa Forest Experiment Station. For. Serv. Dept. Interior. For. Fire Hazard Pap no. 2

INTERNATIONAL CONFERENCE ON

FOREST FIRE RESEARCH

COIMBRA - 19/22 NOVEMBER 1990 - PORTUGAL

Proceedings

Technical Staff

COMPOSITION

Processing: *Fátima Guedes*
Graphic design: *Victor Hugo*
Mounting: *Victor Hugo*

OFFSET SESSION

Photography: *Adelino Bandeira*
Mounting: *Adelino Bandeira*
Transport: *Henrique Taborda*
Printing: *Joaquim Felício*

COVER

Graphic design: *Victor Hugo*
Photography: *José Cabreira*
Printing: *João Carlos*

Published by: International Conference on Forest Fire Research
November 1990

List of Papers

Subject A – General and Institutional Aspects